Seismic Data Acquisition Through Tubing

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Abstract

We have collected good quality crosswell seismic data through production tubing in active oil fields at realistic interwell distances (300 ft). The data were collected at the Aera Cymric field (1998) and at a Chevron site (1997); both located in the Central Valley of California. The Aera data were used to produce travel-time tomographic images of the interwell region. Both sites have similar geology, namely siliceous shale (diatomite) with moderate to highly-attenuating reservoir rocks. In addition we confirmed modeling predictions that typical tubing attenuation losses are on the order of 12 dB. We expect that the use of stronger sources and tube wave suppression will allow for crosswell imaging at realistic distances even for low Q or high noise situations. We are searching for an industrial partner now for a data collection in the gas wells of the San Juan Basin or South Texas.

Introduction

Cross borehole seismic imaging (tomography) has been demonstrated to be a useful tool for the characterization of oil producing reservoirs (Paulsson *et al*., 1992, Lines, *et al*., 1993, Bair, *et al*., 1999). Some of the benefits derived from the use of cross borehole imaging are: 1) enhanced definition of the reservoir, 2) better reservoir management (resulting in increased production, lower costs, and less risk), 3) ability to do time-lapse monitoring of EOR processes (e.g. steam flooding), and 4) enhanced spatial resolution compared to surface seismology.

The application of cross borehole seismic imaging has been somewhat limited in producing oil fields because of the need to remove the production tubing (stopping production and adding cost) before data could be collected. However, with the advent of newer, more powerful sources and advanced data processing techniques, it is now possible to collect quality crosswell seismic data with the production tubing in place.

With overall direction from the Lawrence Livermore National Laboratory (LLNL), and as part of the DOE Borehole Seismic Forum, a partnership which also included Aera, Chevron, Tomoseis, and Lawrence Berkeley National Laboratory (LBNL) was formed to do modeling, and collect and process crosswell seismic data in producing oil fields to demonstrate that quality crosswell seismic data could be collected and processed into useful images (velocity tomograms).

Crosswell Seismic Processing

The crosswell seismic processing flow is illustrated in Figure 1. Initial trace edit and data pre-processing is followed by travel time picking for producing 2-D or 3-D tomograms or velocity "maps" between the wells. This can be considered as a 2-D or 3-D "sonic" log of the reservoir. TomoSeis does not use a standard discretized or pixelated model as has been used in the past due to the inferior resolution afforded by such models. The velocity images derived from the data shown here use a layered model with lateral variations which can handle large dips and large lateral velocity variations. In addition, a full 3-D tomographic solution is available where the structure is extreme. The velocity image produced is depth referenced and no time-to-depth conversions are necessary.

The velocity information is used in reflection imaging, analogous to the way stacking velocities are used in surface seismic processing. As in VSP processing, wavefield separation is used to separate upgoing and downgoing wavefields allowing for a much cleaner stack. The data need to be mapped into the offset-angle domain following ray tracing and wavefield separation. This is performed using the VSP-CDP transform. Final velocity analyses are done to refine and improve the stacked section. Other information, such as shear, mechanical properties, anisotropy, or guided wave (continuity logging) modes can be analyzed as appropriate, and integrated into the overall reservoir model.

Field experiments and results

Crosswell data were collected at the Aera Cymric field (1998) and at a Chevron site (1997); both located in the Central Valley of California. Both sites have similar geology, namely siliceous shale (diatomite) with moderate to highly-attenuating reservoir rocks. In both cases the data were collected and processed by Tomoseis under contract to LLNL.

The signal source was a second generation RCP, or Resonant Cavity Piezo-electric, source. This source uses dual cavities with cylindrical ceramic vibrators to generate a broad bandwidth linear response signal. The source is not clamped to the borehole allowing data to be rapidly logged with the source in constant motion, similar to marine seismic acquisition. We used the Tomoseis "TARS" slim-hole, multi-level receiver system whose characteristics are detailed in Table 1. The data acquisition parameters are outlined in Table 2.

Data were collected at the AERA Cymric site for several configurations of the receiver well including: single casing, double casing, triple casing, and single casing plus production tubing. Figures 2 and 3 show the full wave fields (common receiver gather) and velocity tomogram respectively for a single casing in the receiver well. The first p-wave wave arrivals are well-defined, and no tube waves are in evidence. The interwell spacing is about 300 ft.

Figures 4 and 5 show the full wave fields (common receiver gather) and velocity tomogram respectively for a double casing in the receiver well. The first p-wave arrivals are not as well-defined as for the single casing, but are nonetheless adequate to produce the tomogram of Figure 5. The interwell spacing is also about 300 ft.

Figures 6 and 7 show the full wave fields (common receiver gather) and velocity tomogram respectively for a triple casing in the receiver well. The first p-wave arrivals are not as well-defined as for the single casing, and tube waves are present, but it is possible to produce the tomogram of Figure 7. The interwell spacing is also about 300 ft.

Figures 8 and 9 show the full wave fields (common receiver gather) and velocity tomogram respectively for a single casing plus production tubing in the receiver well. The first p-wave arrivals are well-defined and no tube waves are in evidence. The interwell spacing is also about 300 ft.

It is evident that high quality data can be gathered at moderate Q sites like Cymric, and that tomographic imaging is possible, even through production tubing.

Data were also collected at the lower Q Chevron site. Figures 10 and 11 show the full wave fields (common receiver gather) and velocity tomogram respectively for the no-tubing case. The first p-wave arrivals are well-defined, followed by s-wave arrivals and tube waves. The interwell spacing is about 120 ft.

Figure 12 shows the full wave fields (common receiver gather) for the with-tubing case. Note that the p-wave arrivals are absent, and tube waves dominate. The difficulty here was very high noise from gas in the well. It was noted that the noise levels here in the 300-1000 Hz band were higher than in typical gas wells. It was not possible to produce a tomogram for this case.

Conclusions

Our results show that it is possible to collect high quality crosswell seismic data through production tubing at realistic distances (300 ft) in moderate Q geologies, and that tomographic imaging is possible for these cases. Lower Q or higher noise scenarios will make this more difficult. However, through the use of stronger sources and tube wave suppression it should be possible to do crosswell imaging at realistic distances even for low Q or high noise situations.

Future Activities

We are searching for an industrial partner now for a data collection in the gas wells of the San Juan Basin or South Texas. We expect improved performance by 1) using a stronger source with extended low frequency response, 2) suppressing tube waves in both source and receiver wells, and 3) by developing algorithms for smaller source-receiver vertical offsets. In addition we would like to investigate the use of shear waves (Sv) to investigate fractures and anisotropy, and collect data in higher temperature wells.

Acknowledgements

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References

Paulsson, B., M. Smith, K. Tucker, J. Fairborn, 1992. Characterization of a steamed oil reservoir using cross-well seismology, *The Leading Edge*, v. 11, no. 7, 24-32.

Lines, L., M. Miller, H. Tan, R. Chambers, S. Treitel, 1993. Integrated interpretation of borehole and crosswell data from a west Texas field, *The Leading Edge*, v. 12, no. 7, 13-16.

Bair, J., S. Johnson, D. Julander, R. Langan, J. Meyer, J. Washbourne, 1999. Time-lapse imaging of steam and heat movement in the Cymric 36W Cyclic Steam Pilot using crosswell seismology, SEG Expanded Abstracts, Oct., 1999.

Levels:	5 or 10
Diameter:	1 11/16”
Bandwidth:	150 - 2000 Hz
Depth:	15,000 feet
Temperature:	$150^{o}C$ ($300^{o}F$)
Conveyance:	12 conductor wireline
Pressure Cntl:	grease injector/ lubricator
Sensitivity:	-182 dB

Table 1. TARS receiver specifications

Sample Period:	250 ms
No. of Samples:	6400 (pre-correlation)
No. of Samples:	1600 (post-correlation) or 400ms of data
Sweep frequencies:	150-1000 Hz (low Q formations)
	150-1500 (medium Q formations)
Sweep function:	Linear
Shot Stacks:	4
Receiver Spacing:	2.5 ft
Shot Spacing: 2.5ft	
Receiver System:	10 level

Table 2. Data Acquisition Parameters (Aera)

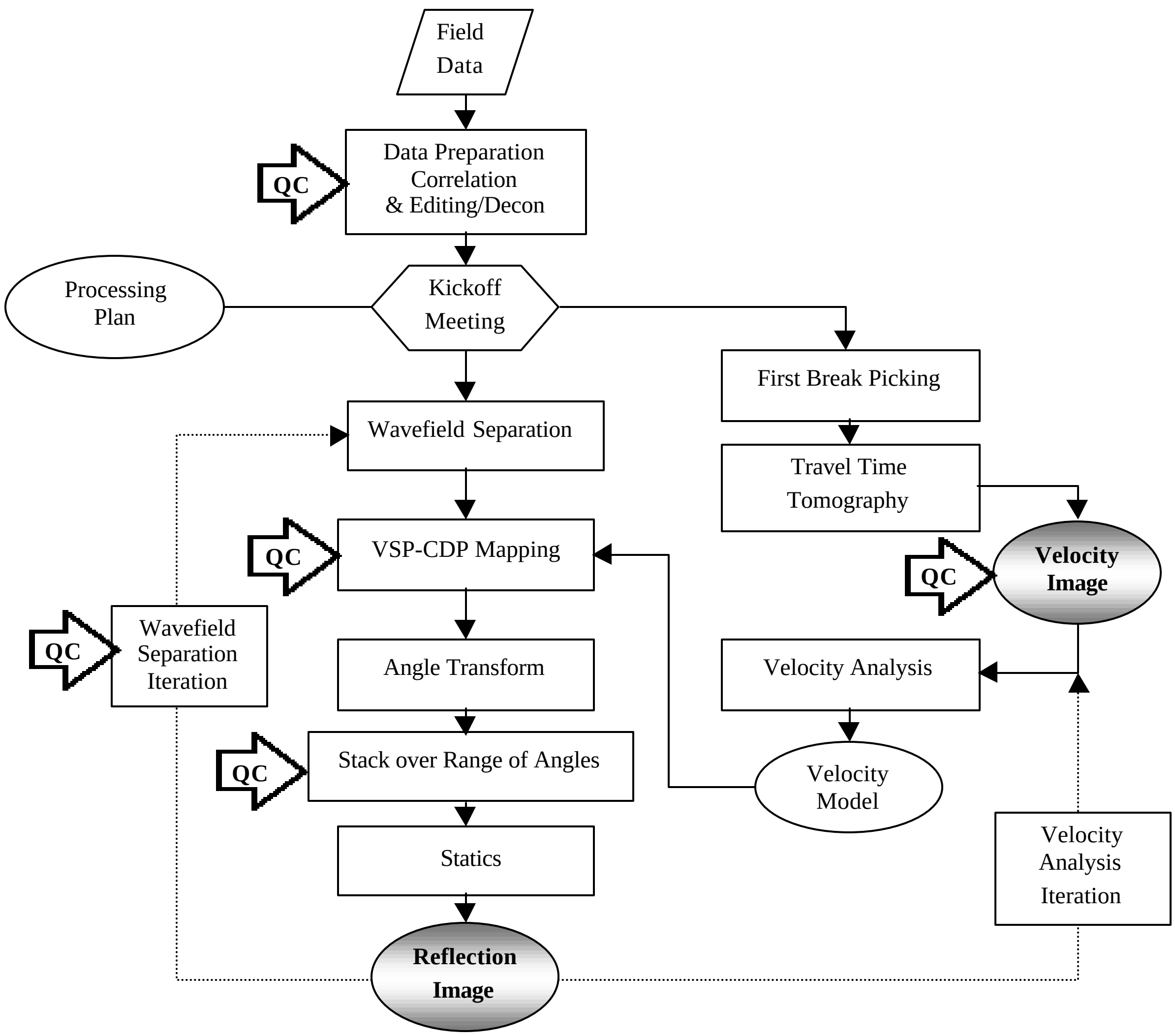

Fig. 1 Crosswell Seismic Processing Flow

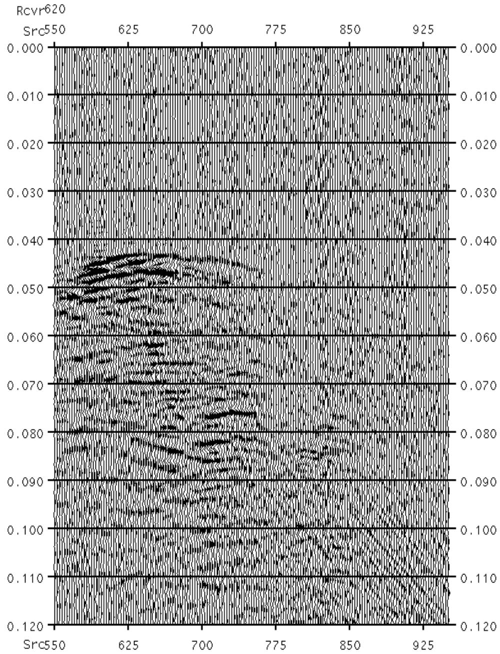

Figure 2. Full wave fields for a single casing at Aera

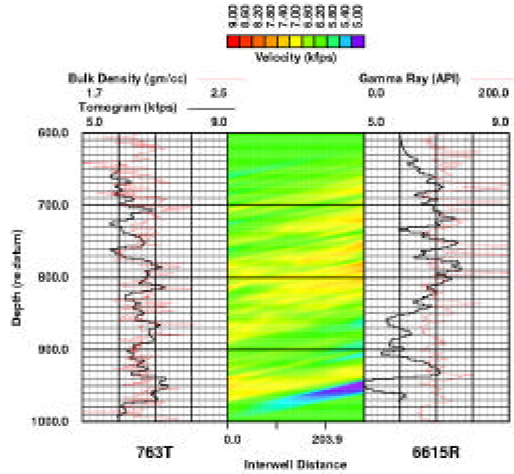

Figure 3. Tomogram for a single casing at Aera

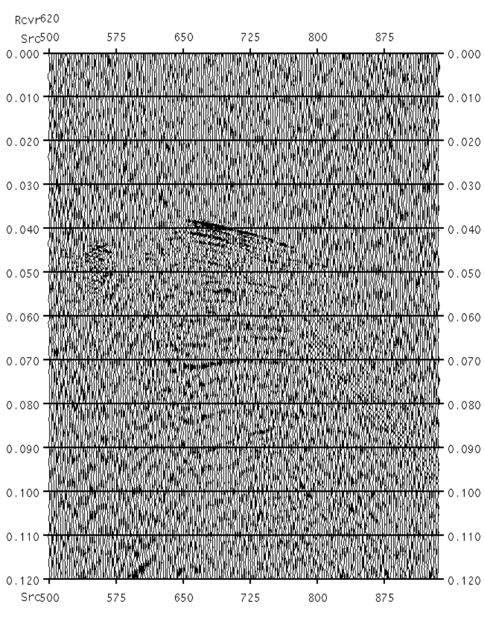

Figure 4. Full wave fields for a double casing at Aera

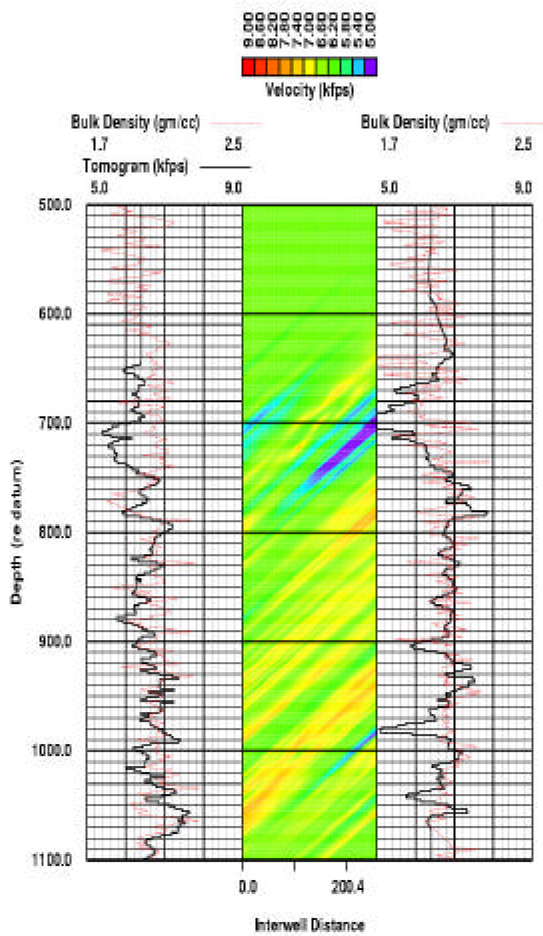

Figure 5. Tomogram for a double casing at Aera

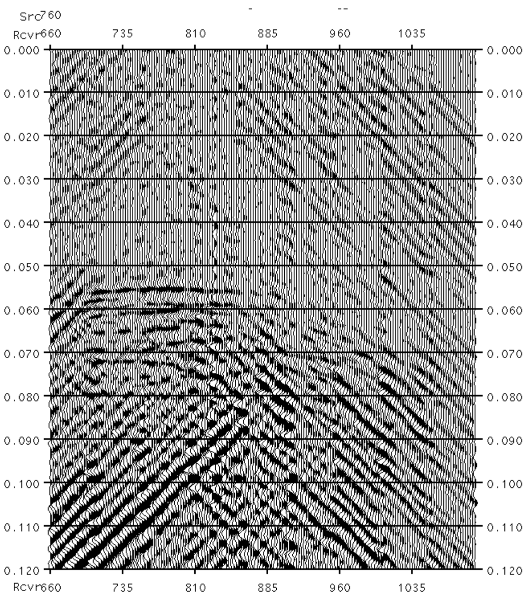

Figure 6. Full wave fields for
a triple casing at Aera

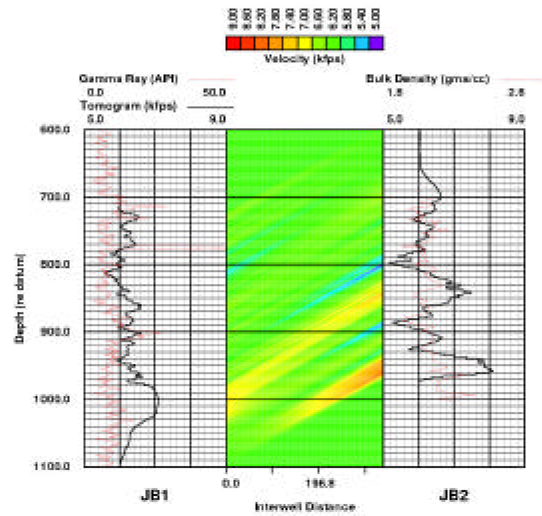

Figure 7. Tomogram for a
triple casing at Aera

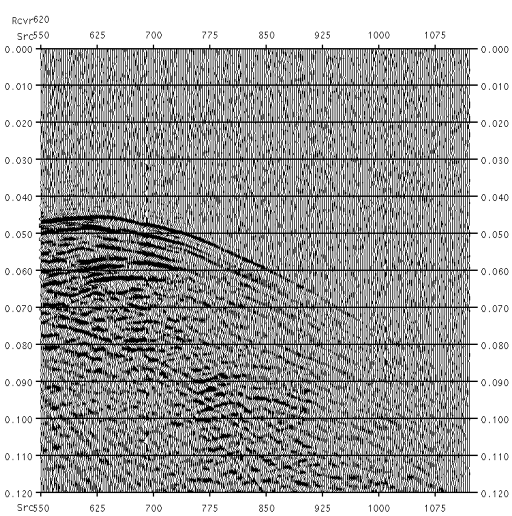

Figure 8. Full wave fields for
a single casing plus production
tubing at Aera

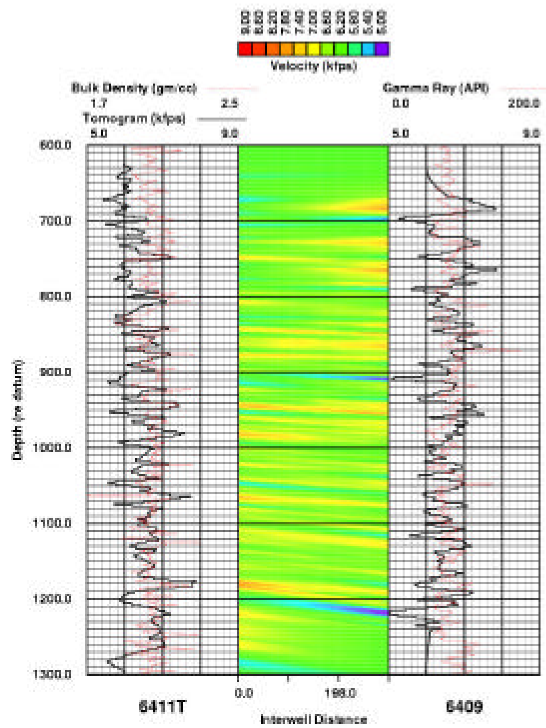

Figure 9. Tomogram for a single casing
plus production tubing at Aera

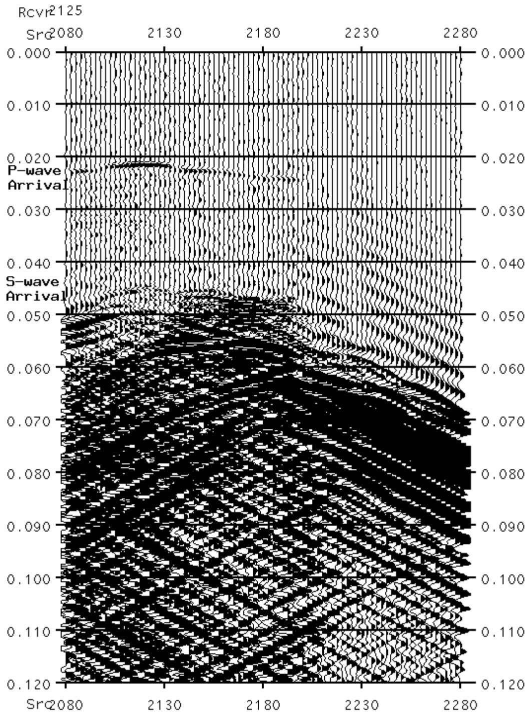

Figure 10. Full wave fields for the no-tubing case at the Chevron site

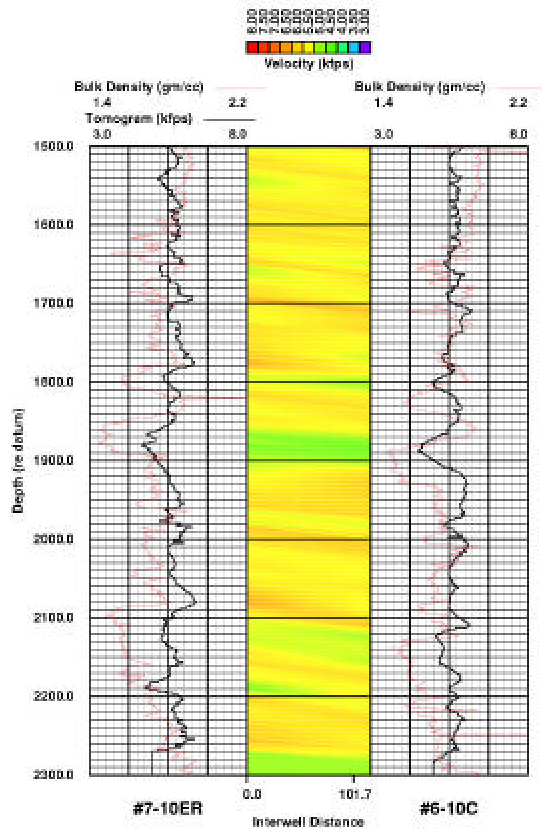

Figure 11. Tomogram for the no-tubing case at the Chevron site

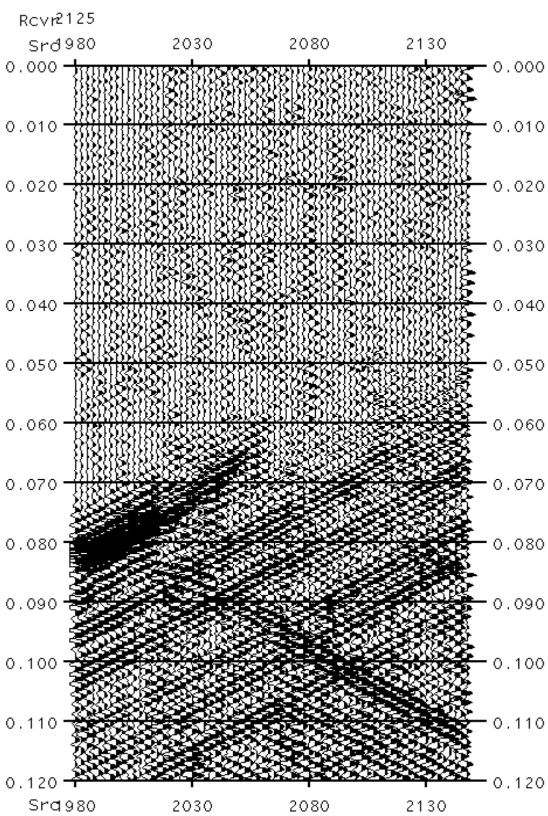

Figure 12. Full wave fields for the with-tubing case at the Chevron site